
The SAE Clean Snowmobile Challenge 2000 – Summary and Results

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ISSN 0148-7191

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Printed in USA

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ABSTRACT

In response to increasing concern about snowmobile noise and air pollution in environmentally sensitive areas, Teton County Wyoming Commissioner Bill Paddleford and environmental engineer Dr. Lori Fussell worked with The Society of Automotive Engineers (SAE) to form and organize a new intercollegiate design competition, the SAE Clean Snowmobile Challenge 2000 (CSC2000). Major sponsors of the CSC2000 included WestStart, Montana Department of Environmental Quality, Teton County Wyoming, SAE, United States Environmental Protection Agency, and Flagg Ranch Resort.

The goal of the CSC2000 was to develop a snowmobile with improved emission and noise characteristics that did not sacrifice performance. Modifications were expected to be cost effective and practical.

The CSC2000 was held in and around Jackson Hole, Wyoming from March 20 – 31, 2000. Participating universities competed against each other in the categories of emissions, fuel economy/range, noise, acceleration, handling, cold-start, hill climb, engineering design paper, oral presentation, and static display. Points were awarded to teams based on their performance in each of the events.

The University at Buffalo won the CSC2000 with a snowmobile featuring a four-stroke engine and catalytic aftertreatment. This first-place entry was successful at reducing noise and emissions while simultaneously improving fuel economy. However, it did experience some loss of performance capability.

The University of Waterloo took second place in the CSC2000 with a snowmobile featuring an advanced two-stroke engine and catalytic aftertreatment. The Waterloo

entry significantly reduced emissions while simultaneously improving performance and fuel economy. However, noise from this entry did not meet competition standards.

INTRODUCTION

Snowmobiles provide hours of exhilarating winter fun for many outdoor enthusiasts. But these fun machines also present an ongoing environmental challenge in the form of excess exhaust emissions and high noise levels.

In an effort to find solutions to the emission and noise challenges presented by snowmobiles, Teton County Wyoming Commissioner Bill Paddleford and environmental engineer Dr. Lori Fussell worked with the SAE to form a new intercollegiate design competition, the Clean Snowmobile Challenge 2000 (CSC2000).

By bringing this new competition to engineering students in both the United States and Canada, CSC2000 organizers brought new energy, ideas, and enthusiasm to a much needed environmental/automotive engineering design problem. Students are quickly committed to making their designs succeed in ways that practicing engineers often fail, due to too many preconceived notions and opinions.

Much of the energy behind the organization of the CSC2000 came from within the community of Jackson Hole, Wyoming. A Jackson Hole-based Advisory Board made up of local land managers, businessmen, snowmobilers, and environmentalists assisted the SAE, Commissioner Paddleford, and Dr. Fussell with the development of the competition.

Major sponsors of the competition included WestStart, Montana Department of Environmental Quality, Teton

County Wyoming, SAE, United States Environmental Protection Agency, and Flagg Ranch Resort. A complete list of all CSC2000 sponsors is located at the end of this paper.

The goals of the CSC2000 were:

- To give a hands-on, team-oriented experience to university students in both engine design and engine control and management systems design.
- To encourage the research and development of advanced snowmobile technology.
- To help facilitate a solution to the controversy surrounding snowmobile use in environmentally sensitive areas.
- To give snowmobilers, outfitters, land managers, government officials, and environmentalists the opportunity to work together to reach a common goal.
- To provide positive publicity opportunities for CSC2000 sponsors and the community surrounding Jackson Hole and Teton County.

COMPETITION OVERVIEW

OBJECT OF COMPETITION

The object of the CSC2000 was to develop a snowmobile that could be used to help solve the controversy surrounding snowmobile use in environmentally sensitive areas. The modified snowmobiles were expected to be quiet, emit significantly less unburned hydrocarbons (UHC) and carbon monoxide (CO) than conventional snowmobiles, and maintain or improve the performance characteristics of conventional snowmobiles. The modified snowmobiles were also expected to be cost-effective; so that snowmobile outfitters could afford to purchase them and still make a profit.

Although the modified snowmobiles competed in several performance events, the intent of the competition was to design a touring snowmobile that would primarily be ridden on groomed snowmobile trails. The use of unreliable, expensive solutions was strongly discouraged.

GENERAL RULES

Each participating university was given a used, 1998 Polaris Indy Trail for modification. This model of snowmobile features a 488 cc, fan-cooled engine and is representative of the type of snowmobile rented to tourists in the Greater Yellowstone Area. Donated snowmobiles had been ridden approximately 16,000 km (10,000 miles).

Students had just six months to make modifications to the engine, suspension, fuel management system, drivetrain, track, skis, and body. Major modification restrictions included:

- The snowmobile's tunnel had to remain stock. The bulkhead had to be commercially available.

- Two-stroke engines were limited to a displacement of 500 cc and four-stroke engines were limited to a displacement of 800 cc.
- Fuel choice was limited to premium gasoline, a blend of 90% gasoline and 10% ethanol, or electricity.
- Turbochargers were not permitted.
- The snowmobile had to remain track driven and ski steered.
- The snowmobile had to be propelled with a variable ratio belt transmission.
- Traction control devices were not allowed.

A complete listing of competition rules and restrictions are available in *The Clean Snowmobile Challenge 2000 Rules* (1)*.

COMPETITION EVENTS AND SCORING

Student teams in the CSC2000 competed in seven dynamic events and three static events. Dynamic events included emissions, fuel economy/range, noise, acceleration, handling, cold-start, and hill climb. Static events included engineering design paper, oral presentation, and static display.

A breakdown of the points that were available for each event is located in Table 1.

Table 1 CSC2000 Events and Available Points

Event	Penalty for Failing Event	Points Available for Relative Performance in Event
Emissions	-200	250
Fuel Economy Range	-100	100
Noise	-100	150
Acceleration	N/A	100
Handling	N/A	50
Cold Start	-100	0
Hill Climb	N/A	100
Engineering Design Paper	N/A	100
Oral Presentation	N/A	100
Static Display	N/A	50
Total Points	-500	1000

COMPETITION ENTRIES

PARTICIPATING UNIVERSITIES

All collegiate chapters of the SAE were invited to submit a proposal to compete in the CSC2000. Seven universities

* Numbers in parenthesis indicate references listed at the end of the paper.

from the United States and Canada were selected to participate. The selected universities were:

- Colorado State University
- Ecole de Technologie Superieure
- Colorado School of Mines
- Michigan Technological University
- University of Waterloo
- Minnesota State University, Mankato
- University at Buffalo, State University of New York

TECHNICAL DESCRIPTION OF ENTRIES

Essentially, three distinct approaches to meeting competition objectives were attempted by CSC2000 participants. They were:

1. A conventional two-stroke engine with improved fuel management and the addition of exhaust aftertreatment.
2. A two-stroke engine featuring direct injection and the addition of exhaust aftertreatment
3. A four-stroke engine featuring electronic engine management and the addition of exhaust aftertreatment.

Of these strategies, there were originally two schools interested in four stroke solutions, three schools interested in pursuing two stroke direct injection solutions, and two schools interested in competing with a more highly controlled two-stroke engine.

However, due to limited development time and other unexpected obstacles, none of the schools interested in direct injection were able to compete with a direct injected two-stroke. Additionally, one of the schools interested in a four-stroke solution abandoned its initial approach. These four teams still competed in the CSC2000, but it is important to note that their entries were essentially put together in the month before the competition took place. They are not representative of the teams' intended design strategy.

Detailed information on each team's intended design strategy, challenges faced, and final results are available in the individual CSC2000 participants' Engineering Design Papers (2-8).

A summary of the snowmobiles as they actually competed in the CSC2000, not as they were intended to compete, is included in Table 2.

EVENT DESCRIPTIONS AND RESULTS

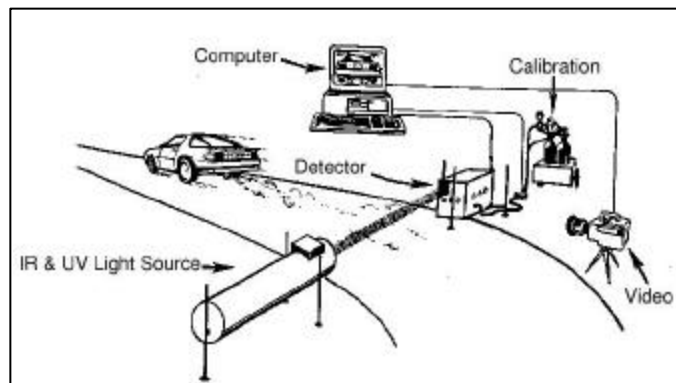
EMISSION TEST

Carbon monoxide (CO) and unburned hydrocarbon (UHC) emissions were measured from all CSC2000

snowmobiles. Emission measurements were taken utilizing the Fuel Efficiency Automobile Test (FEAT) equipment developed at the University of Denver.

The FEAT is an infrared (IR) remote monitoring system for automobile CO and UHC exhaust emissions (9). Figure 1 shows a schematic diagram of the instrument.

Figure 1 Schematic Diagram of the FEAT



The instrument and techniques employed have been fully described in the literature and only a brief overview will be provided here (10,11). The FEAT instrument was designed to emulate the results one would obtain using a conventional non-dispersive infrared (NDIR) exhaust gas analyzer. Thus, FEAT is also based on NDIR principles. An IR source sends a horizontal beam of radiation across a single traffic lane, approximately 10 inches above the road surface. This beam is directed into the detector on the opposite side and divided between four individual detectors: CO, carbon dioxide, UHC, and reference. An optical filter that transmits infrared light of a wavelength known to be uniquely absorbed by the molecule of interest is placed in front of each detector, determining its specificity. Reduction in the signal caused by absorption of light by the molecules of interest reduces the voltage output. One way of conceptualizing the instrument is to imagine a typical garage-type NDIR instrument in which the separation of the IR source and detector is increased from 8 centimeters to 6-12 meters. Instead of pumping exhaust gas through a flow cell, a car now drives between the source and the detector.

The FEAT has been shown to give accurate readings for CO and UHC in double-blind studies of vehicles both on the road and on dynamometers (12-14). Ashbaugh et al. (15) used a fully instrumented vehicle with tailpipe emissions controllable by the driver/passenger in a series of drive-by experiments with the vehicles emissions set for CO between 0-10% and between 0-0.35% (propane) for UHC to confirm the accuracy of the on-road readings. The results are an accuracy of $\pm 5\%$ for CO and $\pm 15\%$ for UHC. Recently, the abilities to measure nitric oxide and exhaust opacity have been added (16).

Table 2 Summary of CSC2000 Modification Strategies

Participant	Engine	Engine Cycle	Engine Management	Fuel Delivery	Cooling System	Fuel	Emission Control Strategy	Noise Control Strategy
Colorado State University	Suzuki Spirit ZRT 600, sleeved to 500cc	Two stroke	Mechanical, lean setting	Carburetors	Liquid	Blend of 10% ethanol and 90% gasoline	Lean burn	Foam, ducting changes
Ecole de Technologie Superieure	Polaris 500 cc	Two stroke	Mechanical, lean setting	Carburetors	Liquid	Blend of 10% ethanol and 90% gasoline	Lean burn	Student built 3-expansion chamber exhaust system, non-sequential
Colorado School of Mines	Polaris 488 cc	Two stroke	DTA Engine control unit	Electronic fuel injection	Air	Blend of 10% ethanol and 90% gasoline	Catalyst, student designed electrostatic precipitator	Foam insulation, sound dampening devices
Michigan Technological University	Polaris 500cc Fuji (Note: finished competition with Polaris 440cc Fuji due to breakdown)	Two stroke	Mechanical	Carburetors	Liquid	Blend of 10% ethanol and 90% gasoline	Partial flow-through catalyst with secondary air injection	Modification to stock muffler, tunnel lined with sound barrier material, hood lined with Dynomat liner and sound absorbing foam, exhaust directed into track
University of Waterloo	Modified Polaris 500 cc	Two stroke	Mechanical, slightly lean setting	Carburetors	Liquid	Blend of 10% ethanol and 90% gasoline	Two way monolithic oxidation catalyst	Student designed silencer, insulation, standard air box design
Minnesota State University	Polaris 500 cc	Two stroke	MoTec M48 electronic control unit	Electronic fuel injection	Liquid	Blend of 10% ethanol and 90% gasoline	Two-way monolithic oxidation catalyst with secondary air injection	Addition of a silencer, Polaris Edge air box, hood and side panel redesign, Dynomat hood liner
University at Buffalo	Polaris Sportsman 500 cc	Four stroke	Magneti Marelli electronic engine management system	Electronic fuel injection	Liquid	Premium gasoline	Close-coupled paladium only catalyst	Muffler, air box, reduction of metal to metal contacts, header wrap, sealed cowl lined with open cell

The FEAT has been easily adapted for measurements of snowmobile exhaust emissions and has been successfully used to make two in-use surveys of snowmobile emissions in Yellowstone National Park in the winter of 1998 and 1999 (17, 18). The FEAT source and detector were placed on insulating pads on top of the snow. Snowmobile exhaust exits at the front of the sleds toward the ground, so the beam height was lowered to approximately 15 cm (6 in) above the snow. Sampling time was extended from 1/2 second for cars to a full second for snowmobiles. This allows additional time for the rear of the sled to clear the beam. To reduce snow spray a plastic artificial snow mat, approximately 1.2 m x 2.4 m (4 ft x 8 ft) in size, was laid on top of the snow directly under the path of the sensing beam. The video camera photographed the front cowling of each sled as it

was measured for a permanent video record of the event. The support equipment was housed nearby in the University's mobile home. The instrument was calibrated before and after each measurement period using a certified gas cylinder (Praxair, Danbury, CT.). Temperature, humidity and pressure were recorded for all of the measurement sessions.

In the CSC2000, the FEAT was used to measure CO and UHC emissions during two different modes of operation:

1. *A gentle acceleration from 0 to 24 km/h (15 mph), to simulate a snowmobile pulling away from an entrance gate* - This mode of testing took place at an altitude of approximately 2000 meters (6,600 feet) above sea level. Temperatures ranged from 4-9°C (40-49 °F).

Relative humidity ranged from 47% and 55%. Wind speed was less than 1 m/s.

2. *A climb up a gentle hill (3 to 4 percent grade) at a constant speed of 32 km/h (20 mph)* - This mode of testing took place at an altitude of approximately 2,260 meters (7,400 feet) above sea level. Temperatures ranged from 4-7°C (39-44 °F). Relative humidity ranged from 48% and 57%. Wind speed was less than 1 m/s.

Professional drivers drove the snowmobiles during the emission tests. Ten measurements of each mode were taken for each snowmobile. The highest and lowest measurements for each mode were thrown out. The remaining sixteen measurements were averaged together to generate each snowmobile's average CO and UHC emission in parts per million (ppm).

CSC2000 participants were expected to reduce the CO emissions of their original snowmobile by at least 25% and the UHC emissions of their original snowmobile by at least 50% to pass the event. Teams that did not meet these minimum reductions received 200 penalty points. Emission reductions were measured relative to a control snowmobile of the same make, model, and usage as the snowmobiles given to CSC2000 participants.

Up to 250 points were available to teams based upon their ability to simultaneously reduce CO and UHC emissions beyond competition minimums. Test results are summarized in Table 3.

The University at Buffalo achieved significant reductions in emissions with its four-stroke design. As indicated in Table 3, UHC emissions were below the limit of

detectability of the CS2000 emission test procedure, a greater than 99.5% reduction. CO emissions were reduced by 46%.

Also achieving impressive results was the University of Waterloo. A 95% reduction in UHC emissions was achieved using an advanced two stroke engine with catalytic aftertreatment. CO emissions were reduced by 47%.

FUEL ECONOMY/RANGE TEST

All CSC2000 snowmobiles completed a trip in Yellowstone National Park that was 143 kilometers (89.5 miles) in length. Participants were required to maintain a speed equal to the legal speed limit. The required speed was occasionally reduced for safety in poor driving conditions.

Trail conditions were hard packed, groomed snow. The temperature during testing was approximately -4°C (25°F).

Snowmobiles began the trip with full tanks. The amount of fuel required to fill the tank upon return was used to award points for this event.

A maximum of 100 points was available for the fuel economy/range event. Teams not completing the event were penalized 100 points. Individual team results for fuel economy/range event are listed in Table 4.

Results of particular interest were seen in both the University of Waterloo and University at Buffalo snowmobiles. The University of Waterloo increased fuel economy to 17.2 mpg and the University at Buffalo increased fuel economy to 27.6 mpg, when compared to the control snowmobile's 12.2 mpg fuel economy. Therefore, the increased cost associated with these

Table 3 Emission Testing Results

Participant	CO (ppm Propane)	CO (% Reduction)	UHC (ppm Propane)	UHC (% Reduction)	Points
Colorado State University	59,900	42%	22,800	-10%	-200
Ecole de Technologie Superieure	57,600	44%	23,500	-13%	-200
Colorado School of Mines	78,100	24%	4,600	78%	-200
Michigan Technological University	66,800	35%	24,500	-18%	-200
University of Waterloo	54,500	47%	1,000	95%	50
Minnesota State University	103,800	-1%	19,600	6%	-200
University at Buffalo	55,700	46%	-200*	>99.5%	50
Control Snowmobile	103,100	N/A	20,800	N/A	N/A

* The negative hydrocarbon value indicates that University at Buffalo's hydrocarbons are below the limit of detectability of this test procedure (approximately 100 ppm propane).

advanced snowmobile designs would be somewhat offset by their reduced fuel costs.

NOISE TEST

All CSC2000 snowmobiles were subjected to noise measurements intended to determine the maximum exterior sound level possible from the competing snowmobiles. Noise measuring equipment was located on the exhaust side of the snowmobile, 15 m (50 ft) from the road. The test layout was as specified in SAE J192 (19).

The noise level measurements were taken in conjunction with the acceleration event. This ensured that snowmobiles were operating at wide-open throttle and were making the maximum amount of noise. Two acceleration runs were made by each snowmobile. Each team's noise level was recorded as the highest of the two noise measurements.

The instrument used for the testing was a Quest Technologies M2400, #JN4070101. The instrument was allowed to equilibrate to ambient temperature for the hour it took to set up the speed trap for the acceleration event. The instrument was calibrated using the calibrator supplied with the instrument, with appropriate corrections for ambient conditions.

The instrument was oriented vertically, with the microphone set 1.5 m (60 inches) above the hard snow surface. A windscreen was in place. Background noise was between 40 to 45 dBA.

The test track was set up near the Cathedral Group turnout in Grand Teton National Park. The snow surrounding the track was about three feet deep of hard pack, covered with 1½ inches of light fluff. The elevation

of the test site was 1920 meters (6295 feet) above sea level. The temperature during testing was approximately -4°C (25°F). The relative humidity was 62%. Wind speed ranged from 2.2-3.5 m/s (5-8 mph).

Snowmobiles louder than 74 dB measured on the A-weighted scale, 50 feet from the road failed the noise event and received 100 penalty points. Snowmobiles quieter than 74 dB were awarded up to 150 points, based upon their relative improvement. Results are presented in Table 4.

The University at Buffalo's snowmobile achieved particularly impressive reductions in noise levels (66 dBA, at wide-open-throttle, 50 feet from the road). The noise emissions from this winning entry are comparable to the noise levels measured during a normal conversation over a banquet table. This shows that it is possible to achieve large reductions in the maximum exterior sound level of snowmobiles.

ACCELERATION TEST

The acceleration event was scored on the basis of elapsed time to 500 feet from a standing start. Student participants drove their own snowmobiles in this event. The event comprised the better of two runs.

CSC2000 acceleration testing took place at the Cathedral Group Turnout in Grand Teton National Park. Conditions were as described in the Noise Test Description.

JACircuits timing equipment was used to measure the elapsed time from 0 to 500 feet for this event. This equipment measures elapsed time between two points using a pulsed infrared light beam at the start and finish line. The timing circuit was calibrated by Performance Timing Systems, to 0.001 seconds. The limit of resolution of the timing equipment was 0.001 seconds.

Table 4 Results of the Fuel Economy/Range Event, Noise Test, and Acceleration Test

Participant	Fuel Economy (MPG)	Fuel Economy Points	Maximum Sound Level dBA	Noise Test Points	Best Acceleration (seconds)	Acceleration Points
Colorado State University	9.7	3	83.4	-100	7.615	80
Ecole de Technologie Superieure	Did not finish (DNF)	-100	DNF	-100	27.971	0
Colorado School of Mines	DNF	-100	75.5	-100	8.277	51
Michigan Technological University	8.4	0	75.4	-100	7.286	97
University of Waterloo	17.2	32	78.3	-100	7.241	100
Minnesota State University	DNF	-100	73.0	18	8.594	39
University at Buffalo	27.6	100	66.8	150	10.025	0
Control Snowmobile	12.2	N/A	75	N/A	7.841	N/A

A maximum of 100 points was available for the acceleration event. Individual team results for the acceleration event are listed in Table 4.

The University of Waterloo won the acceleration event, improving the elapsed time to 500 feet from a standing start by almost 0.6 seconds (over the control). This is notable because this sled also reduced UHC emissions by 95% and CO emissions by 47%. Therefore, reduced emissions do not necessarily produce a reduction in performance.

HANDLING TEST

The handling capabilities of each modified snowmobile were evaluated by professional snow cross drivers. Drivers based their evaluation on the snowmobiles' cornering, ride, engine response, braking, clutching, and overall performance.

A maximum of 50 points was available for the handling event. Individual team results for handling event are listed in Table 5.

COLD START TEST

Because cold starting is essential in a snowmobile, the CSC2000 cold start event was a penalty only event. CS2000 snowmobiles were cold-soaked overnight. Teams had exactly one minute to start their snowmobile. Snowmobiles that did not start within 60 seconds failed the cold start event and received 100 penalty points. Snowmobiles that started within 60 seconds passed the event received zero points. Cold start testing took place at -6°C (22 °F).

Individual team results for the cold start event are listed in Table 5.

HILL CLIMB EVENT

All participants in the CSC2000 were required to compete in the World Championship Snowmobile Hill Climb. The hill climb event was scored based on elapsed time to climb a course up Snow King Mountain. The course was approximately 3000 feet long, had an average grade of 19 degrees (39%), and a maximum grade of 30 degrees (60%). Each team made two attempts at the climb. Professional snowmobile drivers rode the snowmobiles in this event.

The snow conditions at the World Championship Hill Climb were particularly challenging on the day CSC2000 teams participated. In fact, only a small percentage of the professional hill climb entries (which featured special hill climb tracks and traction control devices) reached the top of the course on the day CSC2000 teams competed.

All CSC2000 snowmobiles (except for Ecole de Technologie Superieure's...which had broken down) made it just as far as the professionals that were bogging down. Additionally, Michigan Technological University's snowmobile made it all the way to the top of the course. Individual team results for the hill climb event are listed in Table 5.

ENGINEERING DESIGN PAPER

This event required CSC2000 teams to write an engineering design paper describing their snowmobile modifications. Students were expected to explain why modifications were performed and document the results of their snowmobile development and testing. Students were also expected to include a detailed cost analysis of their modifications (including justification for any increased cost of the snowmobile). Finally, teams were expected to address the durability and practicality of any modifications.

Table 5 Results of the Handling, Cold Start, Hill Climb, Engineering Design Paper, Oral Presentation, and Static Display Events

Participant	Handling Results	Cold Start Results	Hill Climb Results	Engineering Design Paper Results	Oral Design Presentation Results	Static Display Results
Colorado State University	50	0, Pass	0, DNF	81	64	42
Ecole de Technologie Superieure	0, Did Not Finish (DNF)	-100, Fail	0, DNF	72	59	28
Colorado School of Mines	0	0, Pass	0, DNF	67	61	29
Michigan Technological University	0, DNF	0, Pass	100	45	44	30
University of Waterloo	32	0, Pass	0, DNF	84	66	38
Minnesota State University	42	-100, Fail	0, DNF	77	60	34
University at Buffalo	29	0, Pass	0, DNF	63	74	41

CSC2000 engineering design papers were judged on content, organization, use of graphics, and references.

A maximum of 100 points was available for the engineering design paper event. Individual team results for the engineering design paper event are listed in Table 5.

NOTE: University at Buffalo's paper was received two days late. Their engineering design paper score reflects a 20 point late penalty

ORAL PRESENTATION

Each CSC2000 team made a ten-minute oral presentation on the rationale and approach to their snowmobile modifications. A five-minute question and answer period followed each presentation.

In their presentation, teams were expected state clearly how their modified snowmobile addresses the needs of snowmobilers (performance), environmentalists/land managers (noise and emissions), and snowmobile tour operators (cost, durability/re-sale value).

CSC2000 oral presentations were judged on content, format, delivery, effectiveness of visual aids, and ability to answer judges' questions.

A maximum of 100 points was available for the oral presentation event. Individual team results for the oral presentation event are listed in Table 5.

STATIC DISPLAY

As part of the CSC2000, each team placed their snowmobile on display at the World Championship Hill Climb, held March 30th through April 2^d in Jackson Hole, Wyoming. Static displays were expected to focus on encouraging snowmobile outfitters to use the modified snowmobiles as part of their rental fleet and educating snowmobilers about the need to reduce noise and emissions from snowmobiles. Teams were encouraged to put up signs, hand out flyers, and use any other marketing techniques to attract attention to their prototype snowmobile.

CSC2000 static displays were judged on aesthetics, student knowledge, handouts/posters, and overall impression.

A maximum of 50 points was available for the static display event. Individual team results for the static display event are listed in Table 5.

PENALTIES ASSESSED DURING THE CSC2000

In addition to receiving penalties for failing individual events, CSC2000 participants received penalty points for arriving late at the competition, performing unscheduled maintenance on their snowmobile, and/or violating

competition safety rules. The penalty points assessed during the CSC2000 are listed below:

- Colorado School of Mines, -50 points, late arrival
- Colorado School of Mines, -25 points, unscheduled maintenance
- Ecole de Technologie Superieure, -25 points, unscheduled maintenance
- Michigan Technological University, -25 points, unscheduled maintenance
- Minnesota State University, -25 points, unscheduled maintenance
- University at Buffalo, -25 points, unscheduled maintenance

SUMMARY OF COMPETITION WINNERS

The final standings of the participants in the CSC2000 are listed in Table 6.

Table 6 Final CSC2000 Standings

Participant	Finish
University at Buffalo	1 st Place
University of Waterloo	2 nd Place
Colorado State University	3 ^d Place
Michigan Technological University	4 th Place
Minnesota State University	5 th Place
Colorado School of Mines	6 th Place
Ecole de Technologie Superieure	7 th Place

In addition to awards for final overall standing, several category awards were presented to CSC2000 competitors. They are listed below.

- *Best Emissions*: University at Buffalo, SUNY
- *Best Fuel Economy*: University at Buffalo, SUNY
- *Quietest Snowmobile*: University at Buffalo, SUNY
- *Best Design*: University at Buffalo, SUNY
- *Best Performance*: Michigan Technological University
- *Best Wreck*: Colorado State University
- *Phoenix Rising Award*: Colorado School of Mines

CONCLUSION

Through the CSC2000, a first step has been taken to solve the noise and emission challenges presented by snowmobiles. Although many CSC2000 participants would have benefited from additional development time, the results from the first year of the Clean Snowmobile Challenge Collegiate Design Series clearly demonstrate that the noise and emission problems associated with traditional snowmobiles can be solved through advances in engine, noise control, and emission control technology.

Using a four-stroke engine and catalytic aftertreatment, the University at Buffalo (UB) was successful at reducing CO emissions by 46% and UHC emissions by more than 99.5%. The UB snowmobile's maximum exterior sound level was reduced to conversational levels (66 dBA), 50 feet from the road. Additionally, the fuel economy of the UB snowmobile was increased to 27.6 miles per gallon. The only weakness in the UB snowmobile was its acceleration performance, which was decreased by approximately 25%.

The University of Waterloo (UW) entry proved that advanced two-stroke engines show promise as well. The UW snowmobile featured an advanced two-stroke engine with catalytic aftertreatment. The UW snowmobile's CO emissions were reduced by 47% and UHC emissions were reduced by 95%. The fuel economy of the UW snowmobile was increased by 41%, to 17.2 miles per gallon. Additionally, its acceleration performance was 0.6 seconds faster than the control snowmobile. This design, however, was unsuccessful at meeting the stringent CSC2000 noise requirements. Therefore, noise reduction from advanced two-stroke engines remains an issue requiring further research.

ACKNOWLEDGMENTS

The CSC2000 would have been impossible without the sponsorship and/or support of the following organizations: Montana Department of Environmental Quality, Teton County Wyoming, United States Environmental Protection Agency, WestStart, Conoco, Jackson Hole Resort Lodging, Wyoming Business Council, United States Department of Energy, Town of Jackson Wyoming, Tenneco Automotive, Flagg Ranch Resort, Sports Car Club of America, Dana Long Manufacturing, Wyoming Ethanol, Jackson Hole Mountain Resort, Oregon State Snowmobile Association, Canadian Renewable Fuels Association, Exhaust Gas Technologies, Wyoming State Snowmobile Association, PG Formula Company, Hughes Production, Sweetwater County Snowpokes, Jackson Hole Snow Devils, Jackson Hole Conservation Alliance, Wyoming Department of Environmental Quality, Yellowstone National Park, Grand Teton National Park, Jackson Hole Chamber of Commerce, Bank of Jackson Hole, Old Faithful Snowmobile Tours, Snow King Resort, SAE Foundation, Redline Snowmobiles, SouthWest Research Institute, Polaris Industries, Alltrans, Domino's Pizza, Hughes Production Company, Renaissance Resort and Spa, Teton Rental Center & Ski-Doo, and University of Denver.

The authors would like to acknowledge the following individuals for their dedication to the development of the CSC2000: Teton County Commissioner Bill Paddleford, Mrs. Lisa Paddleford, Dr. Jerry Fussell, Mr. Robert Sechler, the CSC2000 Rules Committee, and the CSC2000 Advisory Board.

Finally, we express our appreciation to the faculty and students of our participating universities. You accomplished so much in such a short amount of time. We are grateful for your dedication and innovation.

REFERENCES

1. Fussell, L.M., "The Clean Snowmobile Challenge 2000 Rules", August 1999.
2. Wilson, B., J. H. Mick, and S. Mick, "Development of an Externally-Scavenged Direct-Injected Two-Cycle Engine", Society of Automotive Engineers, SAE 00F-94, September 2000.
3. Seers, P., "Research and Development of the Ecole de Technologie Superieure Clean Snowmobile Challenge 2000 Entry", Society of Automotive Engineers, SAE 00F-96, September 2000.
4. Morrison, B.D., C.J. Callender, D.J. Nelson, A.L. Giesick, J.L. Lau, M. Rivera, R.E. Kopp, A.J. Babb, and J. Pfahl, "Reduction in Emissions and Noise from a 500 cc Snowmobile", Society of Automotive Engineers, SAE 00F-95, September 2000.
5. Miers, S.A., C.A. Anderson, J.C. Vizanko, R.D. Chalgren, "Noise and Emissions Reductions for a 2-stroke Snowmobile", Society of Automotive Engineers 00F-98, September 2000.
6. Hue, S., W.M. Burtch, A. Punkari, J. Nixon, N. Manos, C. Yahoda, J. Dunkley, and R. Fraser, "The University of Waterloo Entry in the SAE Clean Snowmobile Challenge 2000", Society of Automotive Engineers, SAE 00F-99, September 2000.
7. Jones, B., K. Ready, A. Hein, D. Jagusch, J. Mills, J. Olson, M. Price, B. Russenberger, and J. Thoennes, "1998 Polaris Indy Trail: An Entry by Minnesota State University, Mankato in the Clean Snowmobile Challenge 2000", Society of Automotive Engineers, 00F-97, September 2000.
8. Mills, A.J. and A.C. Echter, "Creating a Cleaner Snowmobile", Society of Automotive Engineers, 00F-93, September 2000.
9. Bishop, G.A., J.R. Starkey, A. Ihlenfeldt, W.J. Williams, and D.H. Stedman, "IR Long-Path Photometry, A Remote Sensing Tool For Automobile Emissions", Anal. Chem. 61, 671A-676A, 1989.
10. Guenther, P.L. D.H. Stedman, G.A. Bishop, J.H. Bean, and R.W. Quine, "A hydrocarbon detector for the remote sensing of vehicle emissions", Rev. Sci. Instrum, 66, 3024-3029, 1995.
11. Stedman, D. H, G.A. Bishop, P. Aldrete, and R.S. Slott, "On-road evaluation of an automobile emission test program", Environ. Sci. & Technol. 31, 927-931, 1997.
12. Lawson D.R., P.J. Groblicki, D.H. Stedman, G.A. Bishop and P.L. Guenther, "Emissions from In-use Motor Vehicles in Los Angeles: A Pilot Study of Remote Sensing and the Inspection and Maintenance Program", J. Air Waste Manage. Assoc. 40, 1096-1105, 1990.
13. Stedman, D.H. and G.A. Bishop, "Remote Sensing for Mobile Source CO Emission Reduction", EPA 600/4-90/032, U.S. Environmental Protection Agency, Las Vegas, 1991.
14. Elliott, D., C. Kaskavaltzis and T. Topaloglu, "Evaluation of the Stedman (FEAT) Vehicle Emissions Sensing System," SAE. #922314, 1992.

15. Ashbaugh L.L, D.R. Lawson, G.A. Bishop, P.L. Guenther, D.H. Stedman, R.D. Stephens, P.J. Groblicki, B.J. Johnson and S.C. Huang, "On-Road Remote Sensing of Carbon Monoxide and Hydrocarbon Emissions During Several Vehicle Operating Conditions," Presented at A&WMA International Specialty Conference on PM10 Standards and Non-traditional Source Controls, Phoenix, 1992.
16. Popp, P.J., G.A. Bishop, and D.H. Stedman, "Development of a high-speed ultraviolet spectrometer for remote sensing of mobile source nitric oxide emissions", J. Air & Waste Manage. Assoc. 49, 1463-1468, 1999.
17. Bishop, G.A., D.H. Stedman, M. Hektner, and J.D. Ray, "An in-use snowmobile emission survey in Yellowstone National Park", Environ. Sci. & Technol. 33, 3924-3926, 1999.
18. Morris, J.A., G.A. Bishop, and D.H. Stedman, "Real-time remote sensing of snowmobiles emissions at Yellowstone National Park: An oxygenated fuel study", Western Regional Biomass Energy Program, Lincoln, 1999.
19. Society of Automotive Engineers, "Exterior Sound Level for Snowmobiles – Recommended Practice," SAE J192, March 1985.

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